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REMARKS ON THE MORPHOLOGY OF ARTERIES, ESPECIALLY THOSE OF THE LIMBS.[1]

BY FRANK BAKER, M.D.

IT is generally taken for granted that the variability of arteries is such that they are of but little use in morphological studies. Anatomists are usually of the opinion that since the function of the arteries is to nourish the tissues, their course from the heart to their destination is of too slight importance to the race to have become a fixed character, and all search for law is abandoned. But it is questionable whether some biologists have not too hastily come to this conclusion.

Morphological laws are always obscure when studied in the adult individual alone. To trace them we must examine the different phases of individual development and investigate the anatomy of related forms.

There is a period when the embryo of a vertebrate animal is not provided with a proper vascular system. During the early stages of the segmentation of the ovum, no vessels exist, the young cells receiving the necessary nutriment from an interstitial plasma, as do those of the lowest Protozoa.

This stage is of short duration. Throughout the minute disk-shaped object which is hereafter to be a fully developed vertebrate, certain cells appear, of a slightly reddish color, dotting the disk in a peculiar marbled manner. From their appearance and isolation these are known as *blood-islands*. They touch each other finally as they increase in number, either at some part of

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their contour or by means of processes which they throw out, so that there results a net-work, at first indistinct but gradually increasing in clearness and color as the cells enlarge.

Each of these blood-islands then undergoes vacuolation, a portion of the protoplasmic contents becoming liquified and leaving a cavity. By a budding process new cells are formed in the interior of the mother-cells and becoming detached float free in the fluid which fills the vacuole. At this period, therefore, the blood-islands present an outside cell-wall with a contained fluid in which float free cells or corpuscles, the whole arranged in a close mesh-work.

Next the cell-walls wherever in contact thin away and disappear, there resulting a tube the walls of which are the original cell-walls of the blood-islands, the contents a fluid, plasma, in which swim free blood-corpuscles. There is at first no special difference in size among the vessels thus formed, nor is there any structural difference by which we can distinguish arteries from veins. No trunks or branches can as yet be made out, it is in fact a *capillary plexus* that appears, all vessels lying on the same plane and communicating equally with each other.

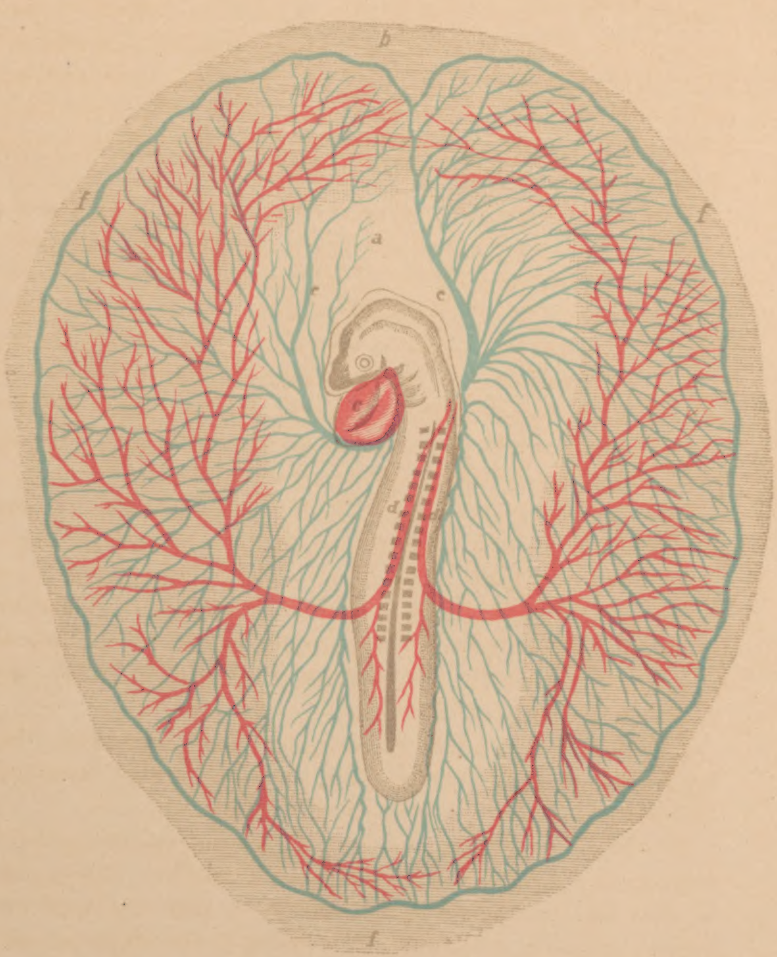
But a difference soon begins to be manifest. The rapidity of growth varies greatly. Along certain lines the vessels begin to increase in size so that soon there is visible distinction of capillaries, branches and trunks. This process of capillary and trunk formation extends from without inward, attains the proper body of the embryo, finally reaching the rudimentary vesicle which represents the heart. (Plate VIII.)

It should be noted that the development is *centripetal.* Nothing is more natural than to look upon the arteries as a system proceeding *centrifugally* from the heart outward.

However convenient this may be to the physiologist or the surgeon, to the anatomist it embodies a fallacy. The capillaries are the first formed, next the arterioles, then the branches of larger size, finally the trunks. It is owing to the subtle persistence of this fallacy that the study of the arterial system has advanced no farther.

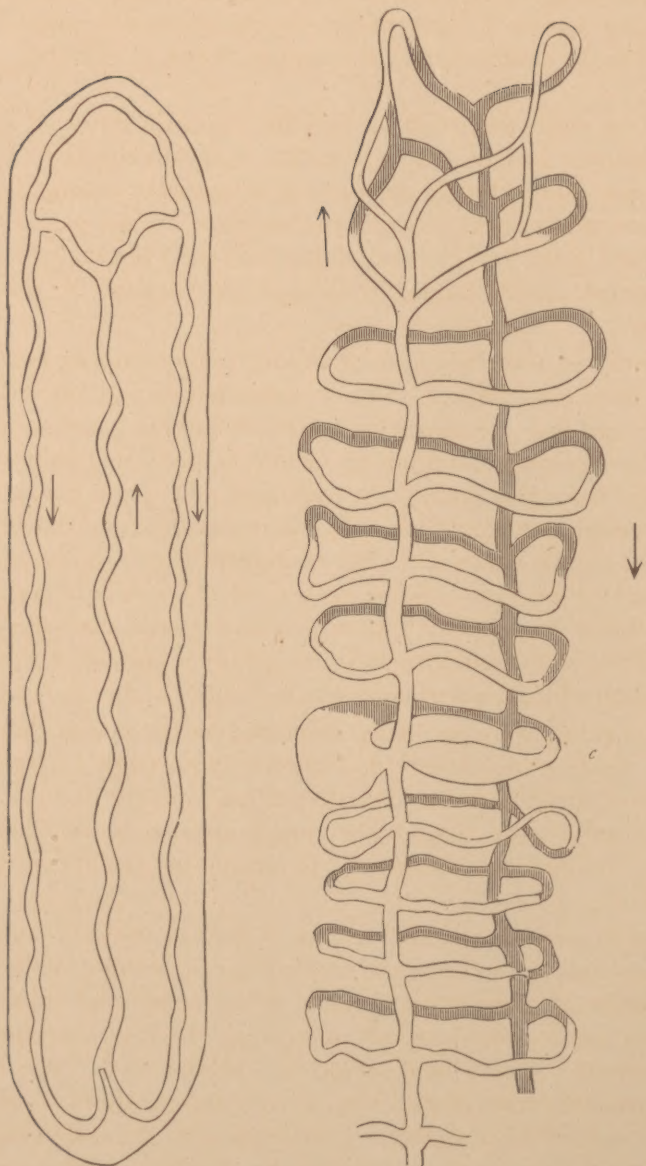
I have mentioned that the rapidity of growth is greater along certain lines, thus leading to the formation of trunks. It is conceivable that these trunk-lines should be intermediate in direction, but in fact they usually become established in certain definite situations. What can be ascertained as to the causes for this?

PLATE VIII.



CIRCULATION IN THE EMBRYO.

PLATE IX.



a *b*

CIRCULATION OF VERMES.

We get but littlé information on this point from the embryo. It will therefore be necessary to examine the vascular system in those animals along which we suppose the line of descent to have passed, getting thereby a fuller history of the successive stages than we can do in the condensed abridgment shown us in embryonic life.

Not until we reach worms do we find the commencement of a true *blood-vascular* system. It is true that even Amœbæ have a trace of vessels formed by the coalescence of vacuoles arising at indeterminate points in the protoplasm, but these are not permanent. In Vermes we have, formed within the layers of the mesoblast, permanent vessels having walls and independent of the body cavity.

In the simplest form we have three longitudinal trunks, two lateral, the third medio-dorsal. Simply connected behind, toward the cephalic end they are somewhat coiled around the ganglionic center which represents the primitive cerebrum, distantly reminding us of the branchial arches of vertebrates. In some genera transverse vessels connect these. This is more distinctly shown in the ringed worms where a distinct transverse trunk exists for each segment of the body. Some portion of these vessels may become pulsatile, sometimes a transverse vessel, sometimes a dorsal one. This is the primitive heart, originally a portion of the tubular system which takes on contraction. (Plate IX. figs. *a*, *b*, *c*.)

Doubtless trunks were originally developed for the reason that fluids will move more rapidly and effectively through a large straight vessel of uniform size than through a capillary network. As these worms move their bodies longitudinally, mechanical force acting on the blood would tend to enlarge the capillaries in that direction.

As to the formation of lateral trunks, it will be noticed that each corresponds to an original segment or somatome of the animal. Each of these somatomes is to be considered morphologically as a semi-detached individual, having its own special nervous system and muscles. Hence each has a semi-independent center of nutritive activity and a lateral trunk for ready and effective supply. Vertebrate animals, including man, share with these lowly organisms this peculiar ramification. The aorta gives off the intercostal arteries which pass around the body and connect with other longitudinal vessels (internal mam-

mary and epigastric). In the lumbar and sacral regions a similar arrangement can be made out, somewhat obscured by the modifications of the abdominal wall. This gives strong support to the theory of the segmentation of the human skeleton. (Plate X.)

What can be said as to the limb-trunks? Let us examine their plan. It will be observed that their bifurcations have a definite relation to the segments of the body. Thus for the pelvic extremity we have first, at the sacro-iliac joint, a division of the common iliac into internal and external iliac; below the hip-joint the main trunk divides into superficial and deep femoral; below the knee another bifurcation gives us anterior and posterior tibial; on reaching the foot there is a division into external and internal plantar, whence radiate branches to the toes.

In the thoracic limb a similar law can be discovered, although the enormous preponderance of the cephalic extremity modifies the vascular supply. The subclavian gives off the thyroid axis after passing the sterno-clavicular joint; the superior profunda represents profunda femoris; the next bifurcation is into radial and ulnar; then the division of ulnar into deep ulnar and superficial palmar arch, whence digital branches. Here again we have a dichotomous division corresponding to segments of the limb, the main trunk dividing after passing the joint.

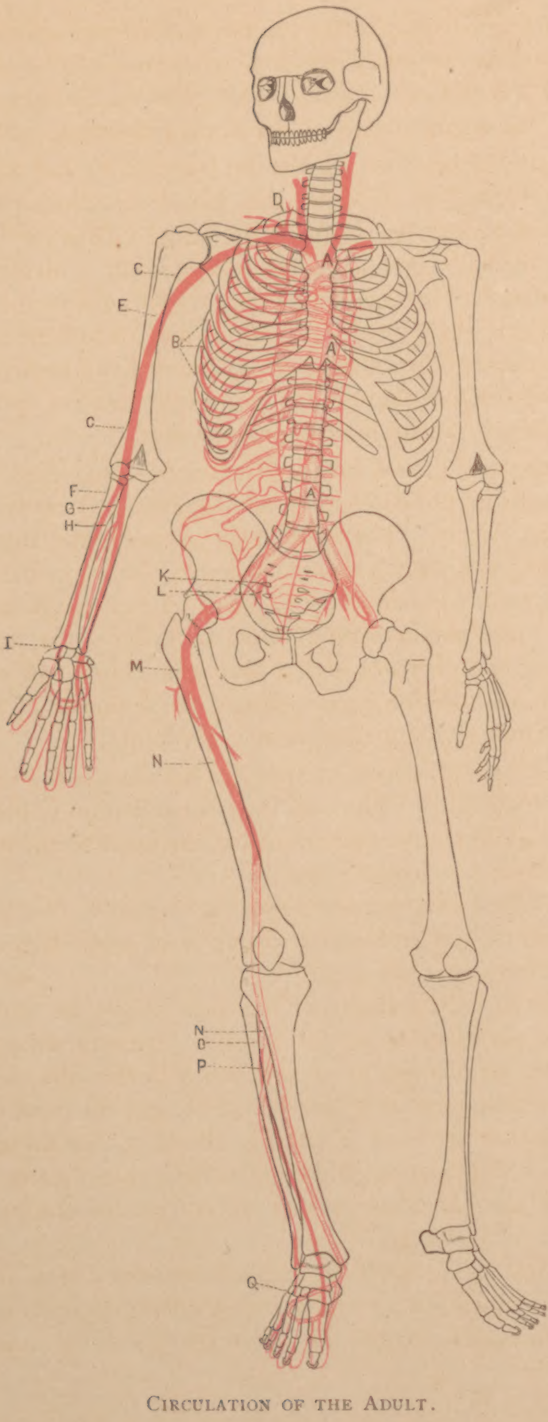
As far as I am aware no attempt has been made to explain this law morphologically. The conditions of nutrition might be met by a single axial trunk extending from the aorta to the phalanges giving off branches irregularly.

If it is urged that simplification of trunks is desirable near movable joints, the numerous examples of high division show that the advantage is not great.

The existing attachments of muscles might be adduced as causing the peculiarities in the vessels. It is true that the deep muscles are segmented in accordance with the divisions of the limbs, but the superficial layers frequently extend from one segment to another or even to a third. Besides, this segmentation also requires explanation, and it is conceivable that it may depend upon the same causes that affect the bifurcation of the arteries.

May it not be possible to explain the division of the limb-arteries by deducing a general law dependent upon some antecedent morphological condition? The arteries of the aortic arch

PLATE X.



CIRCULATION OF THE ADULT.

though greatly variable and complicated in their origin, have been beautifully explained by Räthke and his successors by reference to a general plan of branchial arches, a plan nowhere completely realized, but approximated more or less closely.

If we, in like manner, go back to the primitive limb, we have, according to Gegenbauer, and others, a central stem along which are developed radiate elements at regular distances, each element arising at or near a joint. In the limbs of the higher vertebrates the number of rays is reduced, those on one side being entirely suppressed,

A discussion of the subject would be foreign to the purpose of the present paper. I only wish to point out that the ramification of limb-arteries affords the theory some support. For each original ray would have its separate trunk, and at the convergence of the rays these would fall into an axis trunk. Suppress the rays of one side and a regular dichotomôus division remains. Proceed farther and gradually suppress those of the other side and we might expect to find traces of those latest suppressed in small trunks supplying new structures which came to be formed, having as an indication of their radial character an origin not far removed from the point of segmentation of the limb.

If this is a proper view the internal iliac and profunda femoris in the lower limb, the thyroid axis and superior profunda in the upper may be considered as arteries originally belonging to independent rays now aborted. Of the same category are the interosseous in the arm and the peroneal in the leg.

The operation of this law, if it be such, is obscured in some cases by the formation of anastomoses crossing from one ray to another at the points of segmentation. Thus arise the palmar and plantar arches formed below the carpo-metacarpal and tarso-metatarsal joints

It is also obscured by the operation of two laws derived from the centripetal development of the vascular system. The first of these may be called *variability of convergence.* If some cause slightly diverts a forming trunk from its normal course, the deviation would increase in proportion as it approached the heart, the trunk would debouch at an unusual point and this would cause what is known as an abnormal origin for the artery.

The convergence may be more or less than normal. If more, the origin would be farther from the heart; if less, nearer. When

the arteries of the limbs vary in convergence it is usually a defect, and the bifurcation is, therefore, nearer the heart. The brachial artery divides normally just below the elbow joint, cases of a lower division are so rare that Quinn found but one in 481 cases, and that doubtful because complicated by other anomalies. The same law hold good for other arteries. Now, if the normal point of division is to be considered as the *nodal* point of the archetypal ray, a *slight* variation would carry it to the next higher ray, while the amount must be greater to carry it to a *lower* one. When a high division takes place it is usually near the next higher node. The high division of the brachial is usually as far up as the origin of the superior profunda.

Many examples of this law of convergence are seen in the lower vertebrates. In reviewing these it should be borne in mind that the original main branches of the aortic or spinal trunk are the hypogastric arteries, these being comparatively large vessels before the iliacs appear.

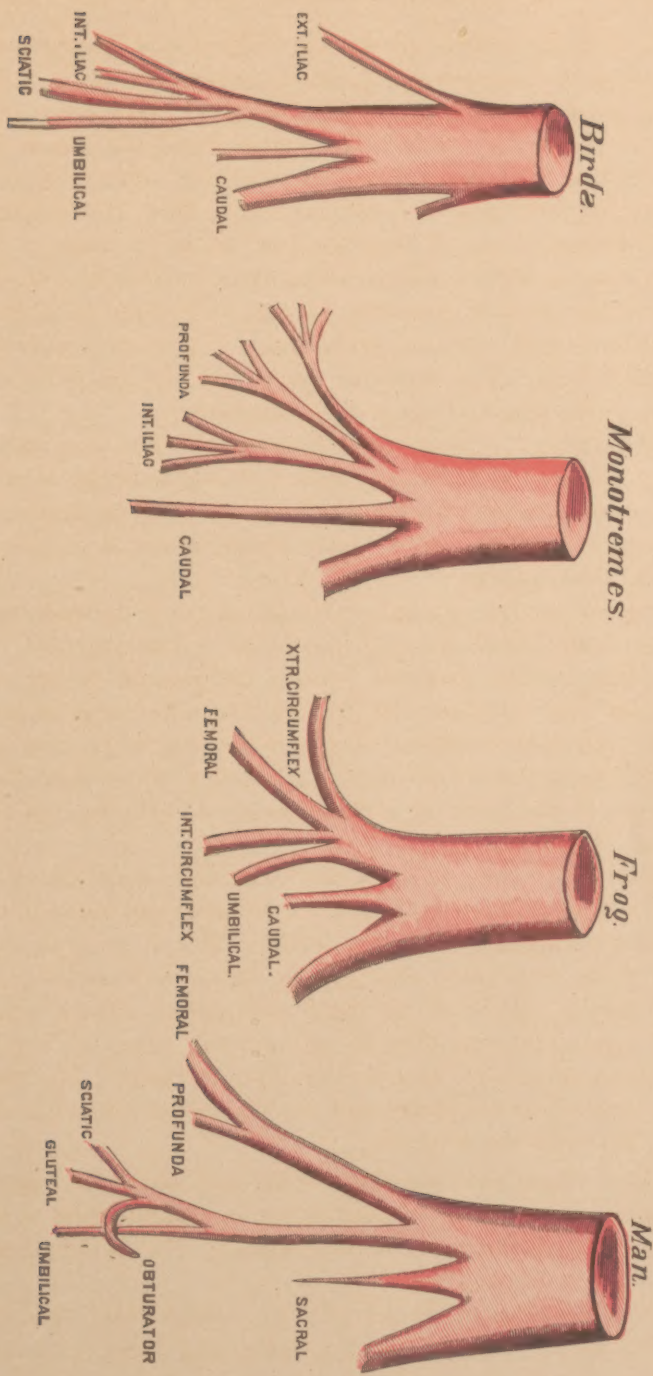
In birds we see the external and internal iliacs derived separately from the aorta — a case of defective convergence. In Ornithorhynchus the profunda femoris, the femoral proper and the internal iliac all come off together—another case of high division. A similar condition obtains in the frog, where two vessels, called the external and internal circumflex, whose homology is unknown to me, come off at the same point as the femoral and umbilical. (Plate XI.)

Another law creating diversity may be termed intersubstitution. A trunk may be diverted from its usual situation and found in the line usually occupied by a smaller vessel. This, it is supposable, may be from some cause affecting the fœtus, such as pressure, force of gravity, embolism, or those unexplained causes which we call atavism or reversion to an ancestral type. A similar phenomenon takes place after the ligation of vessels. The main trunk is reduced or disappears and the channel of collateral circulation becomes the main one.

Another striking example of this is the case where the femoral artery becomes posterior, passing down in the situation of the arteriole known as the comes nervi ischiadici. This is the normal arrangement in birds. (Plate XI.)

Functional activity of the parts to be supplied may undoubtedly considerably modify the size and arrangement of arteries.

PLATE XI.



DIVISIONS OF THE AORTA.

The variation of the long thoracic and uterine arteries in females when lactation and gestation are established, is a familiar example. In animals that move slowly or remain for some time under water, it seems to be sometimes necessary to provide for a slow purling of blood along nervous trunks. In sloths, the Ornithorhynchus and the manatee the main trunks break into plexiform arrangements, and in Cetacea large plexuses encircle the spinal cord. It is conceivable that the original capillary form has never been entirely overcome in these cases. So too in the alimentary canal of man. This, the oldest part of the body when viewed phylogenetically, has also the oldest form of circulation. The activity required is slow, but constant. Removed from external influences, it has not become as highly differentiated in function as the periphery of the body. The polypoid activity of the cells is best kept up by a gradual welling of the blood through a series of encircling capillaries. Even the larger branches show that they are incompletely differentiated. The branches of the mesenteric arteries do not each separately carry blood to the part they are to feed, but unite by cross anastomoses in a series of loops, the whole resembling an enormously enlarged capillary plexus.

If this view of arterial morphology be correct, all varieties found in man and animals should be reducible to the general case prefigured by the radiate fin of fishes. Any important series of exceptions that cannot be derived from the archetype would overthrow the theory.